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SUBMISSION OF SUBSTITUTE SPECIFICATION

Sir:

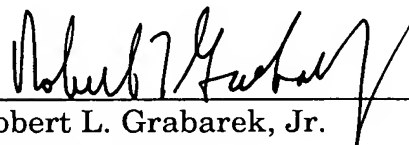
Attached is a Substitute Specification and a marked-up copy of the original specification. I certify that said substitute specification contains no new matter and includes the changes indicated in the marked-up copy of the original specification.

Respectfully submitted,

CROWELL & MORING LLP

Dated: August 15, 2006

By



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METHOD AND APPARATUS FOR THE MANUFACTURE OF A
SURFACE ON A GAS TURBINE BLADE

BACKGROUND AND SUMMARY OF THE INVENTION

[0001] This application claims the priority of International Application No. PCT/DE2005/000222, filed February 10, 2005, and German Patent Document No. 10 2004 008 027.5, filed February 19, 2004, the disclosures of which are expressly incorporated by reference herein.

[0002] The invention relates to a process for the manufacture of adapted, fluidic surfaces.

[0003] Gas turbine blades, in particular those for aircraft engines, as a rule, are made as forged elements, in which case the gas turbine blades are provided with machining allowances in the region of their flow inlet edge as well as their flow outlet edge. If such gas turbine blades are to be used, for example, in the manufacture of an integrally bladed rotor, a so-called Blisk (Bladed Disk) or Bling (Bladed Ring), the gas turbine blades must be machined in the region of the flow inlet edge and flow outlet edge, before the blades are mounted to the rotor, in order to provide adapted, fluidic surfaces in the region of the flow inlet edge as well as the flow outlet edge.

[0004] Referring to prior art, the gas turbine blades are machined in order to manufacture adapted, fluidic surfaces in the region of the flow inlet edge as well as the flow outlet edge in that the gas turbine blades are milled in order to remove excess material and are subsequently manually round to ensure fluidic surfaces in the region of the flow inlet edge as well as the flow outlet edge. Manual rounding is time-consuming, expensive and cannot be reproduced. A manual rounding of gas turbine blades to provide adapted, fluidic surfaces in the region of the flow inlet edge as well as the flow outlet edge, therefore, represents an overall disadvantage.

[0005] German Patent Document DE 199 22 012 C1 relates to a process for the manufacture of adapted fluidic surfaces on integrally bladed rotors. The process described there is used after the gas turbine blades have been manually rounded in the region of their flow inlet edges as well as their flow outlet edges and joined to the rotor in a material-closed manner. The process in accordance with DE 199 22 012 C1 is used for machining gas turbine blades joined to the rotor in the region of the blade pans, i.e., in the region of a suction side, as well the pressure side thereof. However, this process is not used to manufacture fluidic surfaces in the region of the flow inlet edge and the flow outlet edge of gas turbine blades before the gas turbine blades are joined to a rotor in a material-closed manner.

[0006] Based on this, the object of the present invention is to provide a novel process for the manufacture of adapted, fluidic surfaces.

[0007] This object is achieved by means of a process for the manufacture of adapted, fluidic surfaces. In accordance with the invention, the process comprises at least the following steps: (a) generating a nominal milling program for the manufacture of fluidic surfaces in the region of one flow inlet edge and/or one flow outlet edge for an ideal gas turbine blade; (b) measuring the area of an actual gas turbine blade in the region of one flow inlet edge and/or one flow outlet edge thereof; (c) generating a milling program adapted to the actual gas turbine blade in order to manufacture fluidic surfaces in the region of the flow inlet edge and/or the flow outlet edge for the actual gas turbine blade, whereby measured values determined in step (b) are used to adapt or change the nominal milling program generated in step (a) to the milling program for the actual gas turbine blade; (d) manufacturing of the fluidic surfaces on the actual gas turbine blades in the region of the flow inlet edge and/or the flow outlet edge by milling with the use of the milling program generated in step (c), whereby, in a first partial step, coarse-milling, in particular roughing, is used to remove material in the region of the flow inlet edge and/or the flow outlet edge, and whereby, in an adjoining second partial step, fine-milling, in

particular planing, is used to automatically round the flow inlet edge and/or the flow outlet edge.

[0008] Within the meaning of the present invention, a process is suggested with which gas turbine blades can be fully automatically machined in the region of their flow inlet edges as well as their flow outlet edges. Within the meaning of the present invention, the removal of material in the region of the flow inlet edge and flow outlet edge, as well as the rounding of the edges, is performed fully automatically by milling, so that the manual rounding required by prior art can be omitted. Consequently, time and costs for the manufacture of fluidic surfaces on gas turbine blades can be significantly reduced. Furthermore, reproducible manufacturing outcomes can be achieved.

[0009] In accordance with an advantageous development of the invention, the actual gas turbine blade is measured in such a manner that, in the region of the flow inlet edge and/or in the region of the flow outlet edge, respectively one series of measuring points is determined on a suction side and on a pressure side of the gas turbine blade, whereby each of these four series of measuring points consists of several measuring points distributed over the height and/or length of the flow inlet edge and/or the flow outlet edge. The series of measuring points determined on the suction side is used to change the nominal milling paths affecting the flow inlet edge and the flow outlet edge in the region of the suction side in such a manner that each nominal path point of these nominal milling paths having a corresponding measuring point is shifted by the value of deviation between the ideal gas turbine blade and the actual gas turbine blade in the region of the suction side. An interpolation is performed for the nominal path points of this nominal milling path for which such points no corresponding measuring point is available. The procedure is analogous for the pressure side. Likewise, an interpolation is performed for the nominal milling paths located between the nominal milling paths of the suction side

and the nominal milling paths of the pressure side in order to adapt the paths to the actual gas turbine blade.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Preferred developments of the invention are disclosed in the description hereinafter. Referring to a drawing, one exemplary embodiment of the invention will be explained, without, however, being restricted thereto. It shows:

[0011] Fig. 1 is a sectional view of a schematic cross-sectional profile of a gas turbine blade in the region of the flow inlet edge of the gas turbine blade.

DETAILED DESCRIPTION OF THE DRAWINGS

[0012] Referring to Fig. 1, the present invention will be explained in greater detail hereinafter.

[0013] Fig. 1 is a sectional view of a gas turbine blade 10, in cross-section. Thus, referring to Fig. 1, a pressure side 11 and a suction side 12 of the gas turbine blade 10, as well as a flow inlet edge 13 thereof, are shown, the inlet edge 13 providing a transition between the pressure side 11 and the suction side 12 of the gas turbine blades 10. A flow outlet edge, which also provides a transition between the pressure side 11 and the suction side 12 and is provided on the opposite end of the gas turbine blade 10, is not shown in Fig. 1.

[0014] As is illustrated in Fig. 1, the gas turbine blade 10, which has preferably been configured as a forged element, is provided – in unfinished state – with a machining allowance 14 in the region of the blade's flow inlet edge 13. It is now within the meaning of the present invention to suggest a process for the manufacture of adapted, fluidic surfaces on gas turbine blades in the region of their flow inlet edge as well as their flow outlet edge, whereby the process is used to automatically remove the machining

allowance 14, on one hand, and, after removal of the machining allowance 14, this process is used to automatically round the gas turbine blade 10 in the region of the flow inlet edge as well as the flow outlet edge, in order to manufacture – in a fully automatic manner and without manual machining – adapted, fluidic surfaces in the region of the flow inlet edge as well as the flow outlet edge.

[0015] Within the meaning of the inventive process, a nominal milling program is generated for the manufacture of fluidic surfaces in the region of a flow inlet edge and a flow outlet edge for the gas turbine blade. The nominal milling program comprises, in the region of the flow inlet edge as well as in the region of the flow outlet edge, several nominal milling paths for the ideal gas turbine blade. Consequently, considering the region of the flow inlet edge as well as the region of the flow outlet edge, respectively one nominal milling path is located in the region of the suction side, respectively one nominal milling path is located in the region of the pressure side, and preferably – interposed between these two nominal milling paths – several nominal milling paths for the transition region between the suction side and the pressure side are provided. Each of these nominal milling paths for the ideal gas turbine blade comprises several nominal path points.

[0016] Now, in order to adapt this nominal milling program for the ideal gas turbine blade to a real gas turbine blade, an actual gas turbine blade to be machined in the region of the flow inlet edge and the flow outlet edge is measured during a second step. In so doing, the actual gas turbine blade is measured in that, in the region of the flow inlet edge as well as in the region of the flow outlet edge, i.e., on the suction side and on the pressure side of the gas turbine blade, respectively, a series of measuring points is determined. Consequently, a total of four series of measuring points are determined: a series of measuring points for the flow inlet edge in the region of the pressure side, a series of measuring points for the flow inlet edge in the region of the suction side, a series of measuring points for the

flow outlet edge in the region of the pressure side and one additional series of measuring points for the flow outlet edge in the region of the suction side. Each of these four series of measuring points comprises a plurality of measuring points which are distributed over the height and/or length of the flow inlet edge and the flow outlet edge. The series of measuring points determined when measuring the actual gas turbine blade are used in a third step in order to adapt the nominal milling program to the actual gas turbine blade and thus determine a milling program for this gas turbine blade.

[0017] Therefore, after the actual gas turbine blades have been measured, a milling program adapted to the actual gas turbine blade is generated for the manufacture of fluidic surfaces in the region of the flow inlet edge and the flow outlet edge of the actual gas turbine blade, whereby the measured values or series of measured values determined when the actual gas turbine blade was measured are used to change the nominal milling program generated for the ideal gas turbine blade. To achieve this, the nominal milling program, on one hand, and the measured values determined when the actual gas turbine blade was measured, on the other hand, are computed together in such a manner that the result is a milling program for the actual gas turbine blade.

[0018] In order to simplify the illustration of the inventive process, it shall be assumed hereinafter that, in order to manufacture fluidic surfaces within the region of the flow inlet edge 13 of the actual gas turbine blade 10 as shown in Fig. 1, a milling program comprising a total of five milling paths is determined, namely a milling path 15 in the region of the pressure side 11, a milling path 16 in the region of the suction side 12, and a total of three milling paths 17 located between these two milling paths 15 and 16 for the transition between the pressure side 11 and the suction side 12. These five milling paths 15, 16, 17, as already shown above, are generated, on one hand, based on the corresponding nominal milling paths of the ideal gas turbine blade as well as on two series of measuring points which result

from a measurement of the actual gas turbine blade on the flow inlet edge 13 in the region of the suction side 12 and of the pressure side 11.

[0019] In order to determine the milling path 15 in the region of the pressure side 11 of the actual gas turbine blade 10, within the meaning of the invention, the corresponding nominal milling path of the ideal gas turbine blade is computed with the series of measured points determined in the region of the flow inlet edge 13 on the pressure side 11. To accomplish this, a deviation between the ideal gas turbine blade and the actual gas turbine blade is determined for each available measuring point. Then, considering each nominal path point of the corresponding nominal milling path, for which such point a corresponding measuring point is available, the nominal path point is shifted by the value of the deviation between the ideal gas turbine blade and the actual gas turbine blade. Considering the nominal path points, for which no corresponding measuring point is available, an interpolation is performed, i.e., a spline interpolation, among the nominal path points for which corresponding measured values are available. Therefore, the milling path 15 for the flow inlet edge 13 in the region of the pressure side 11 is determined in this way.

[0020] A similar procedure is used to determine the milling path 16 in the region of the suction side 12. Also, considering this milling path 16, a corresponding nominal milling path is computed with the series of measuring points for the flow inlet edge 13 in the region of the suction side 12. In so doing, the series of measuring points of the flow inlet edge 13 determined in the region of the suction side 12 is used to change the respective nominal milling path in such a manner that each nominal path point of the respective nominal milling path, for which a corresponding measuring point is available, is shifted by the value of deviation between the ideal gas turbine blade and the actual gas turbine blade in the region of the suction side 12. Considering the nominal path points of the respective nominal milling path, for which no corresponding measuring point is available, again, a spline interpolation is performed. Therefore, the milling

path 16 for the flow inlet edge 13 in the region of the suction side 12 is generated in this way.

[0021] As already mentioned above, a total of five milling paths 15, 16 and 17 is required for the manufacture of the flow inlet edge 13 in the exemplary embodiment of Fig. 1, whereby, however, considering milling paths 15 and 16, series of measuring points are only available in the region of the pressure side 11 or of the suction side 12. Considering the nominal milling paths affecting the transition region between the pressure side 11 and the suction side 12, no such series of measuring points are available. Therefore, in order to determine the milling paths 17 of the actual gas turbine blade, which are used to manufacture the surfaces in the transition region between the pressure side 11 and the suction side 12, interpolations are performed among series of measuring points in the region of the pressure side 11 and the suction side 12. These, too, are spline interpolations.

[0022] The milling paths for the actual gas turbine blade, which have been determined in the aforementioned manner based on the nominal milling paths of the ideal gas turbine blade and the series of measuring points of the actual gas turbine blade, form a milling program, in which case, with the use of this milling program in a fourth step, the fluidic surfaces on the actual gas turbine blade are manufactured.

[0023] In so doing, during a first partial step, the machining allowance 14 is removed by coarse-milling and, during a subsequent, second partial step, the flow inlet edge 13 is automatically rounded by fine-milling in order to provide the fluidic surface. Coarse-milling is also referred to as roughing; fine-milling is also referred to as planing. The above-described determination of milling paths for the actual gas turbine blade relates to milling paths for fine-milling, i.e., for the automatic rounding of the gas turbine blades in the region of the flow inlet edges as well as the flow outlet edges.

[0024] Following the above-described process for manufacture of the adapted, fluidic surfaces, the gas turbine blades can be joined to a rotor by linear friction welding. It is also possible, to subject the surfaces of the gas turbine blades to subsequent re-machining, for example, by chemically aided vibratory grinding.